Search for Magnetic Monopoles at the RHIC

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for the Monopole Group
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Motivation

- 1269: French military engineer Pierre de Maricourt studied magnets
- 1873: Maxwell equations; It can be symmetrized

$$\nabla \bullet \vec{E} = 4\pi\rho \qquad \nabla \times \vec{B} = \frac{1}{c}\frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c} j$$

$$\nabla \bullet \vec{B} = 0 + 4\pi\rho_m \qquad \nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} - \frac{4\pi}{c} j_m$$

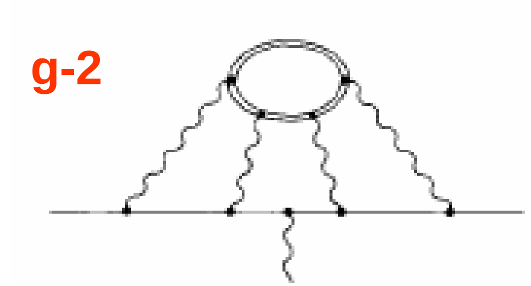
1931: Dirac - Quantization of electric charge : eg = n$\hbar$c/2 n=1,2,3,…
g_D=$\hbar$c/2e=e 137/2; g = ng_D; r_e=$e^2/m_e c^2$=r_M=$g^2/m_M c^2$; m_M=2.4 GeV

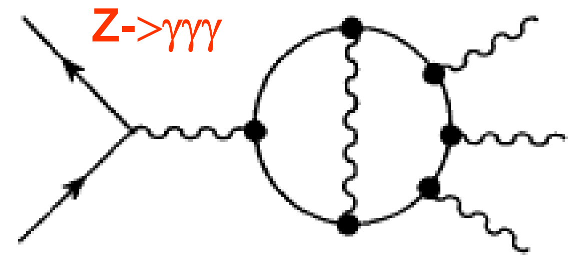
1974: t'Hooft and Polyakov - GUT of Strong and Electroweak interactions: (SU(5)->U(1)) MM mass ~ GUT scale = 10^{16} - 10^{17} GeV

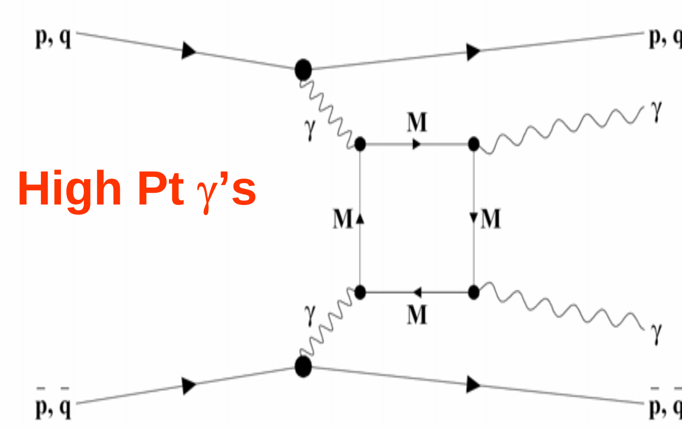
1980-1990: Colored monopoles; Intermediate Mass MMs; Extra Dimensions, Superstring, Proton decay

Magnetic Monopole mass predictions

Electron radius	= 2.4 GeV
GUT	~ 10^{16} – 10^{17} GeV
Electroweak	~ 50 GeV – 10^4 GeV
Super String	~ 10^3 – 10^5 GeV
g-2 of muons	> 240 GeV
Z->$\gamma\gamma\gamma$	> 400 GeV
High P_t γ's	> 610 GeV s=0
High P_t γ's	> 870 GeV s=1/2
High P_t γ's	> 1570 GeV s=1

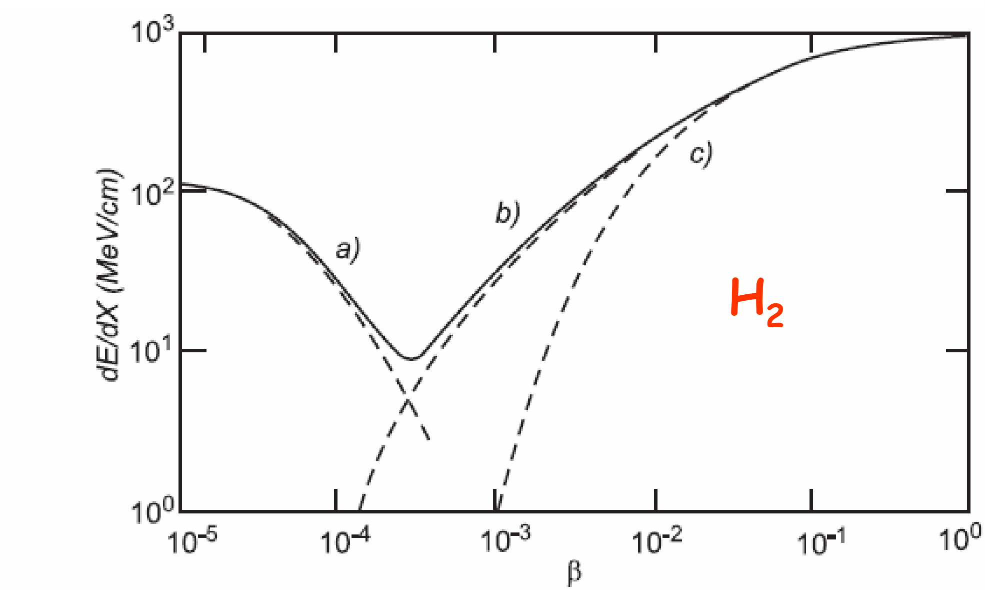


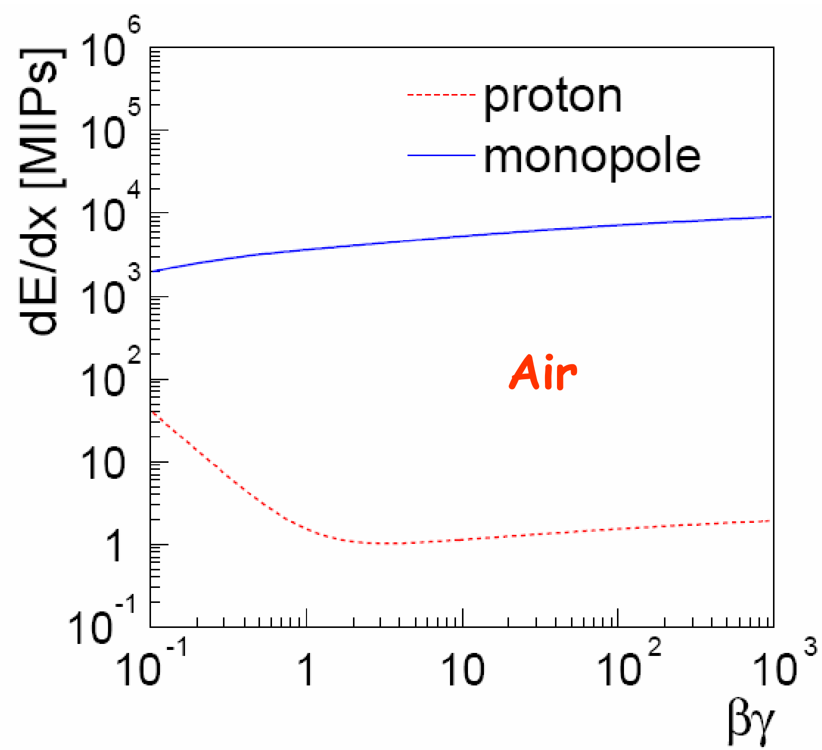




Magnetic Monopole Properties

- Coupling constant $\alpha_{MM}=g^2/\hbar c = e^2/\hbar c\ [g/e]^2=34.25>>1$
- Coupling constant $\alpha_{em}= e^2/\hbar c = 1/137<<1$
- Trajectory in Manetic field: hyperbola in r-z plane
- Energy gained in a B field : W = ngBl, few GeV/kGm
- Ionization a la Bethe-Bloch $(Ze)^2\text{->}(g\beta)^2$ for $\beta= 1$, $(dE/dx)_{MM} = 4700\ (dE/dx)_{mip}$





Search for Magnetic Monopoles

- **Direct experiments:** A large variety of devices to detect the signature of MM passage
- Search MMs in Cosmic Rays
- Search MMs stopped in mater (lunar rocks, earth ore)
- Search MMs at the accelerators
- **Indirect experiments:** Measurements of multi-photon production at the accelerators

Searches at accelerators:
Cross section upper limits vs MM mass

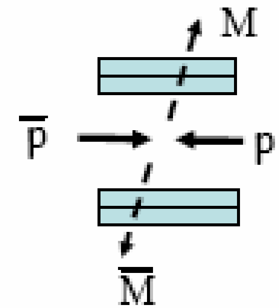
Searches in Cosmic Rays:
Flux upper limits vs MM velocity

Searches for classical MMs at accelerators

$$e^+e^- \rightarrow M\,M\,, \quad \bar{p}p \rightarrow M\,\overline{M}\,, \quad pp \rightarrow pp\,M\,\overline{M}$$

• **Direct experiments**

poles produced - detected immediately (large dE/dx)



Searches with

scintillation counters

nuclear track detectors

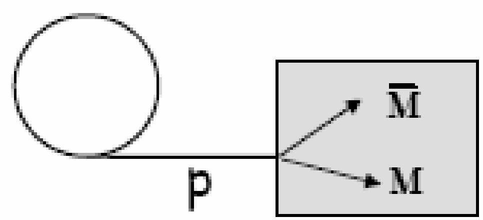
Limits (95 % CL) $\sigma\,(e^+e^-) < \sim 10^{-37}\ \mathrm{cm}^2$ $m_M < 104\ \mathrm{GeV}$

$\sigma\,(\bar{p}\,p) < 2\times 10^{-34}\ \mathrm{cm}^2$ $m_M < 850\ \mathrm{GeV}$

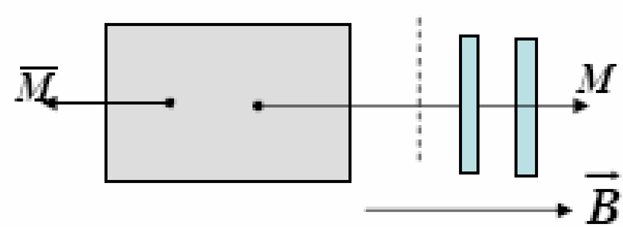
e p

• **Indirect expts**

MMs $\begin{cases}\text{Produced}\\ \text{Stopped}\\ \text{Trapped}\end{cases}$



Later $\begin{cases}\text{Extracted}\\ \text{Accelerated}\\ \text{Detected}\end{cases}$

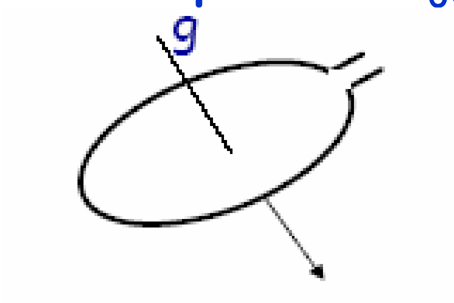


Others

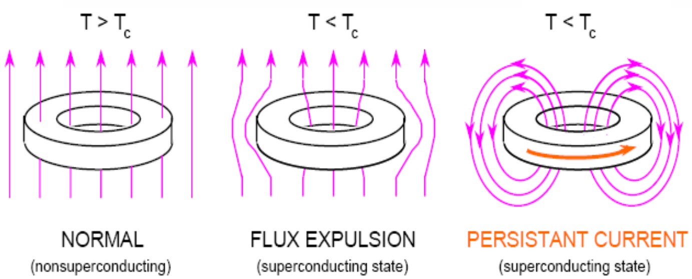
Induction Devices

Method depends only on long range electromagnetic interaction.

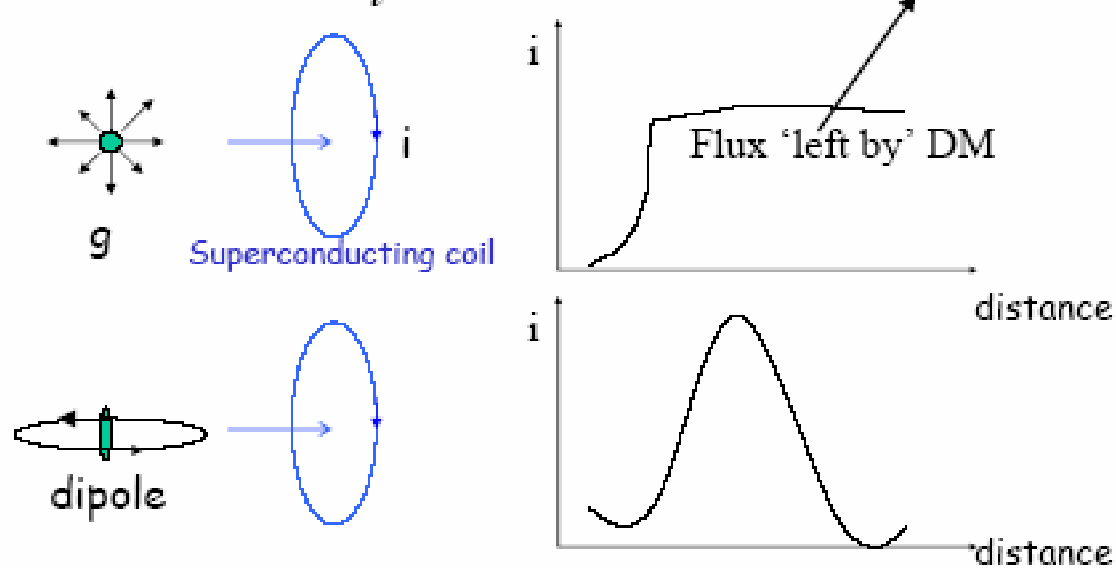
Superconducting solenoid: $\Delta_i = 4\pi N g_D / L = \Delta\Phi / L$; **The change in flux induced by a monopole is** $2\Phi_0$, **where** $\Phi_0 = 2.07\times10^{-15}$ **Wb is flux quantum.**

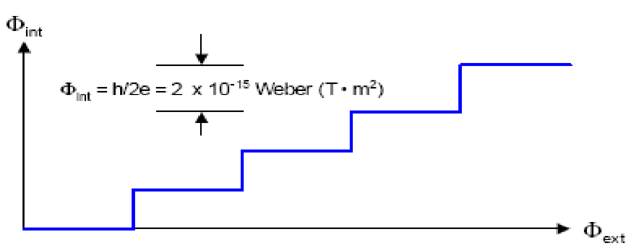


$$\nabla\times\hat{E} = -\left(\mu_0\hat{j}_m + \frac{\partial\hat{B}}{\partial t}\right) \longrightarrow i = -(\Phi + \mu_0 g)/L$$

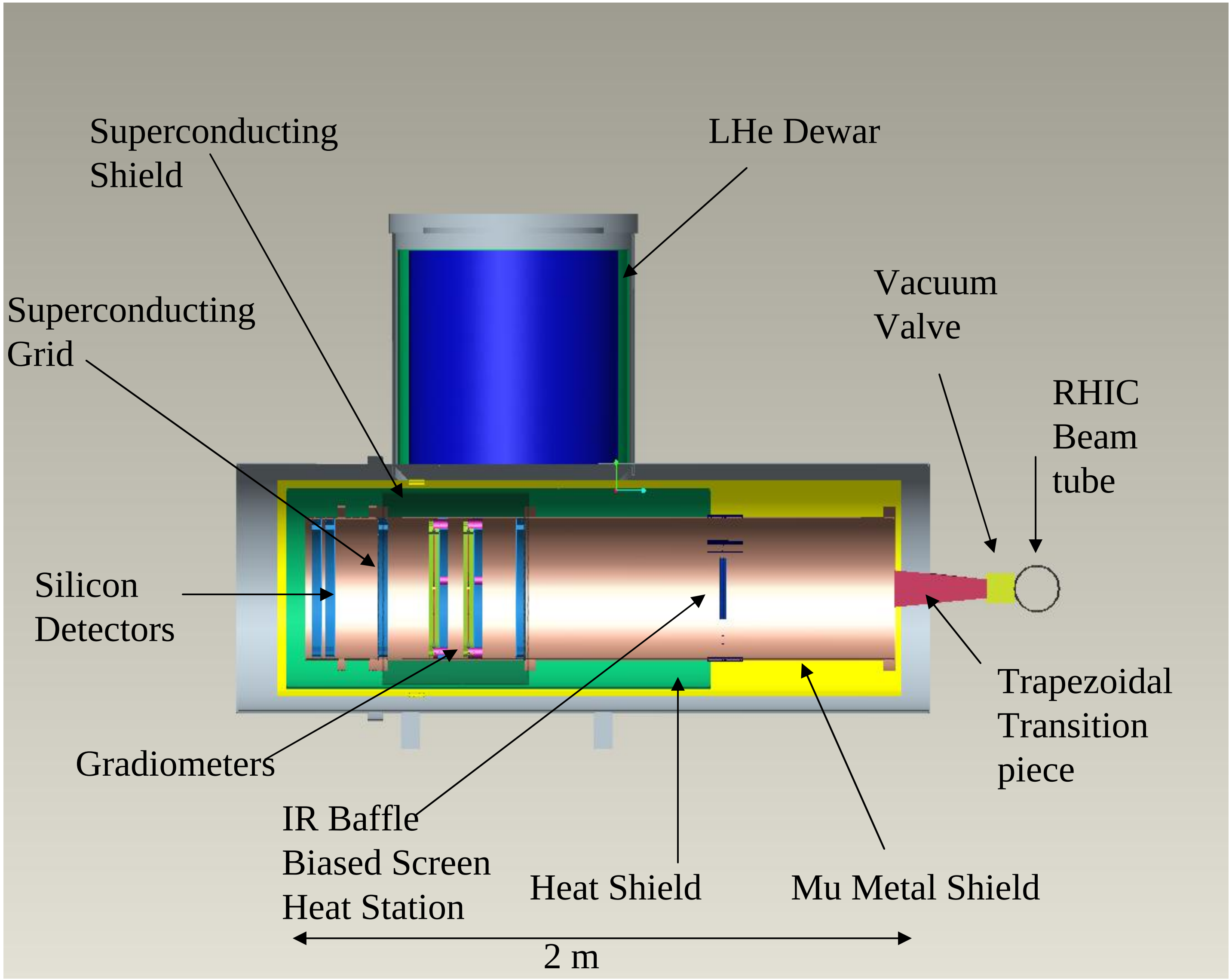


Meissner effect in a superconducting ring cooled in an externally applied magnetic field.

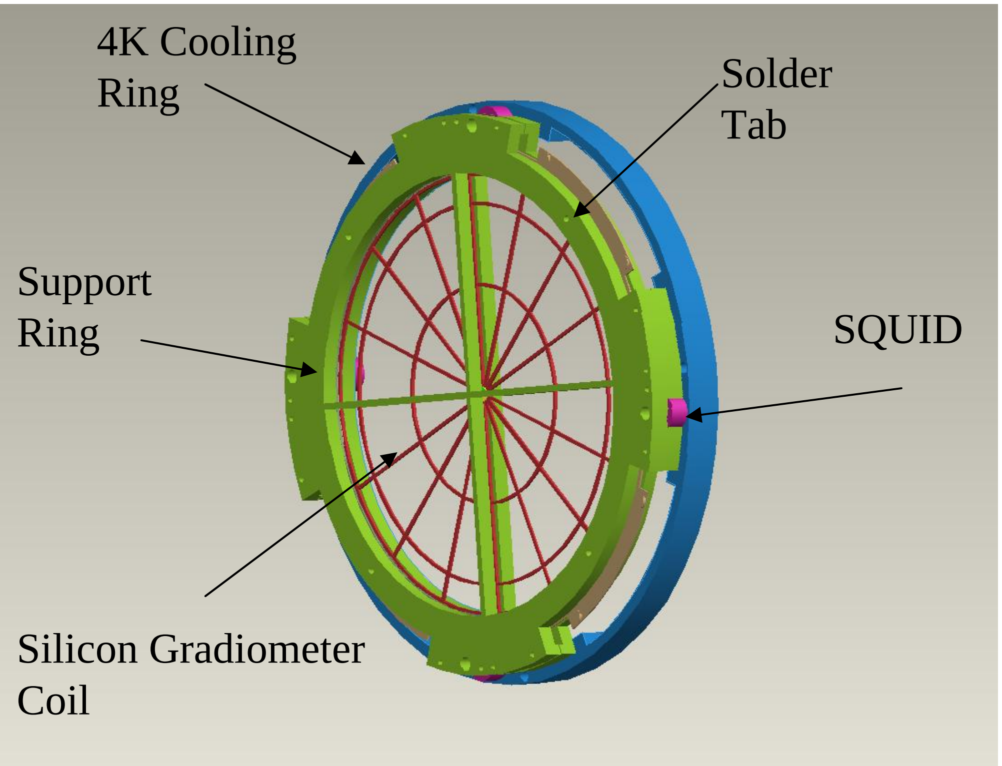


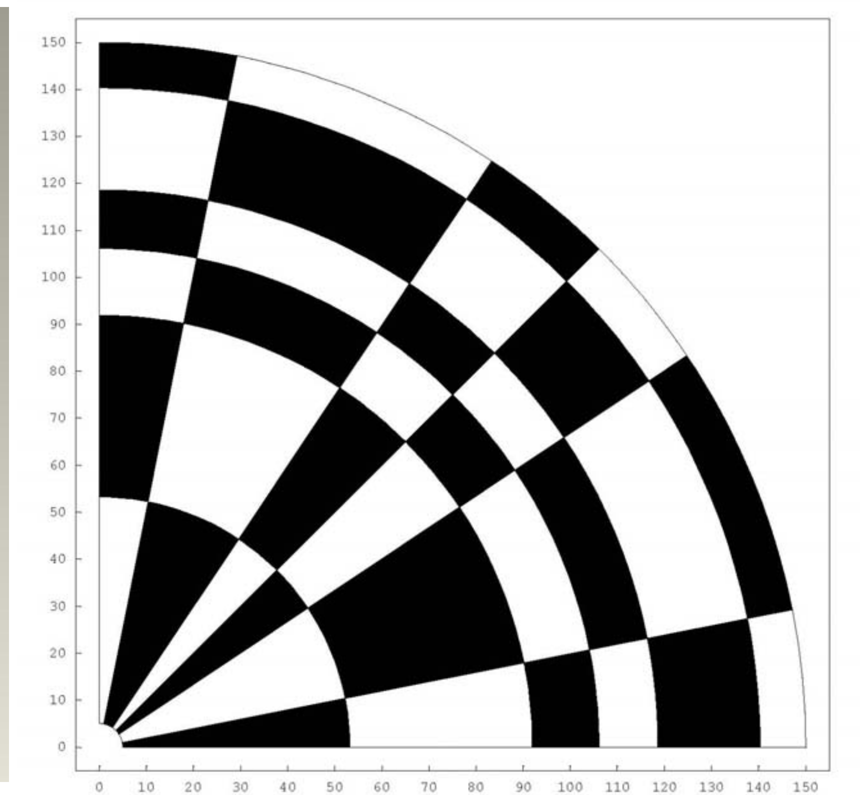


BNL Monopole Detector Setup

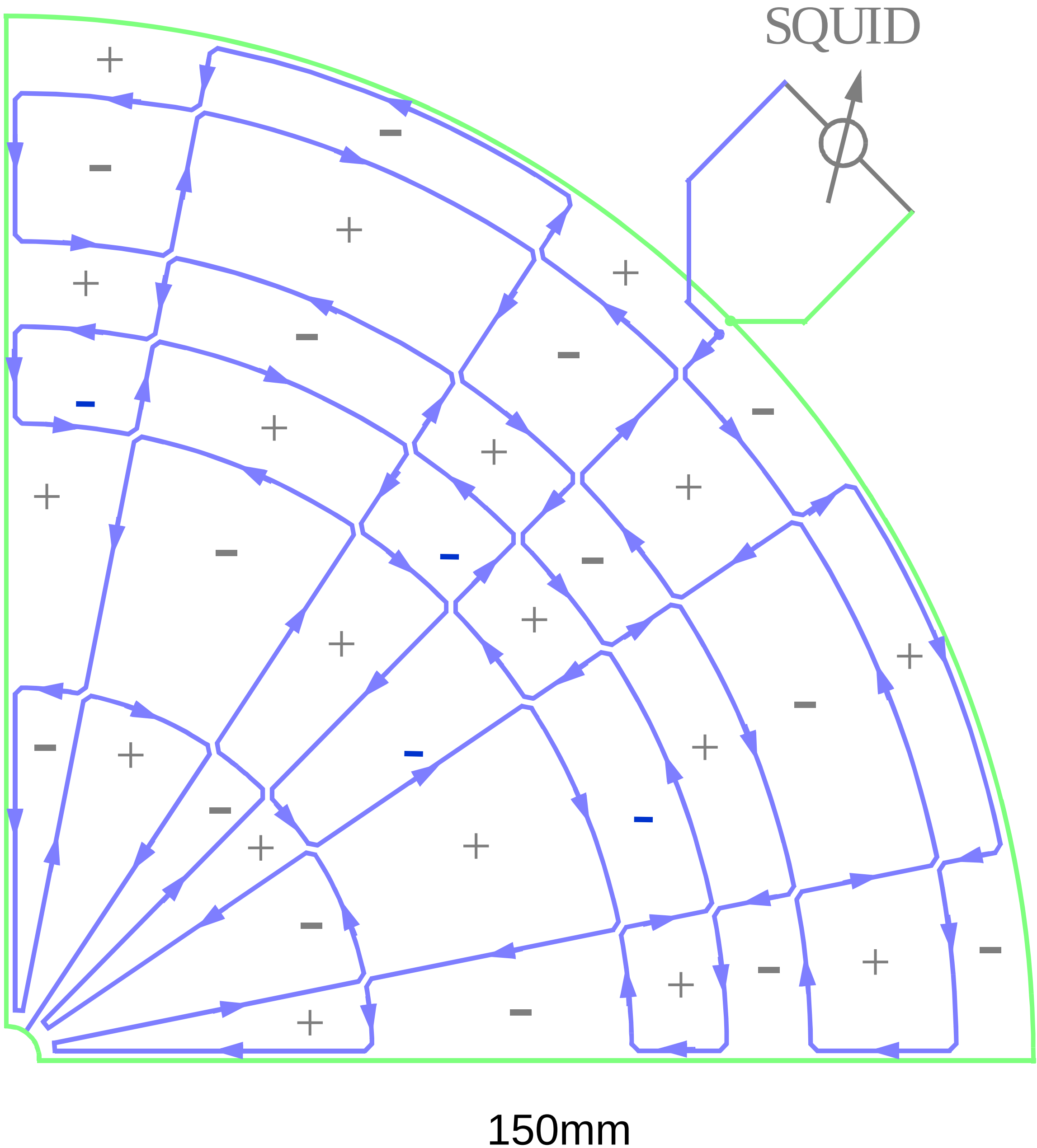


Gradiometer Assembly and Silicon Detector





Third Order Gradiometer



- 3^{rd} or 4^{th} order gradiometer coils are being investigated

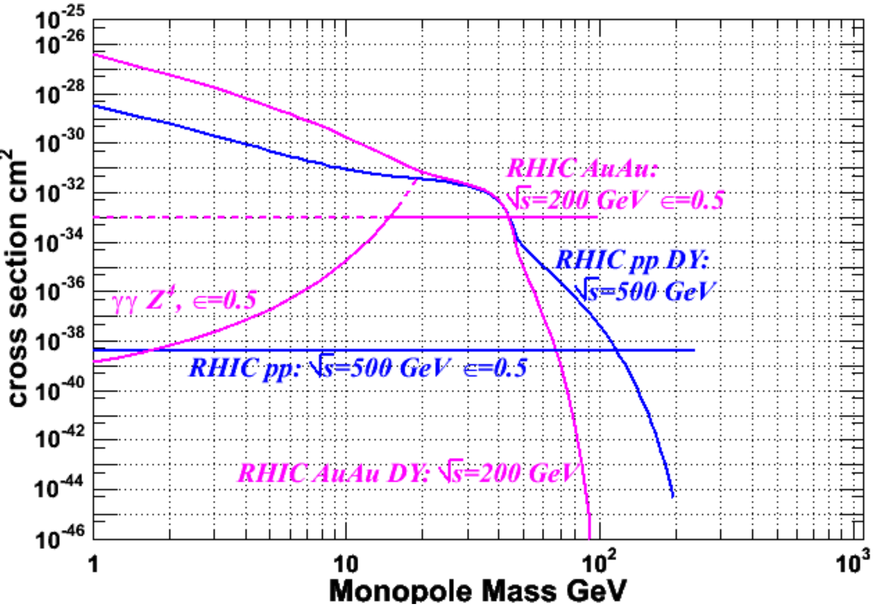
- $L_{3rd} \sim 2\mu H$

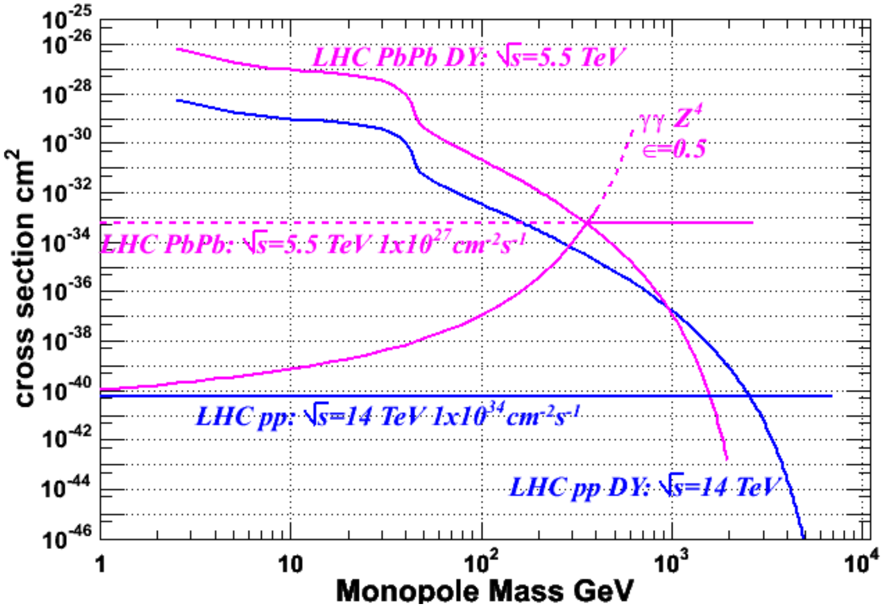
- $L_{4th} \sim 3\mu H$

- 3^{rd} order gradiometer cancels polynomial terms up to 25^{th} degree to better than 1%

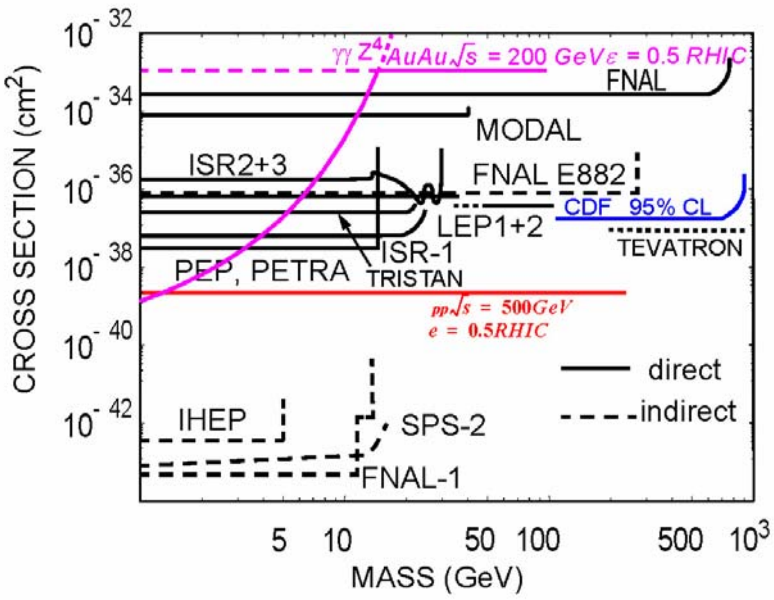
- 4^{th} order gradiometer cancels polynomial terms up to 75^{th} degree to better than 1%

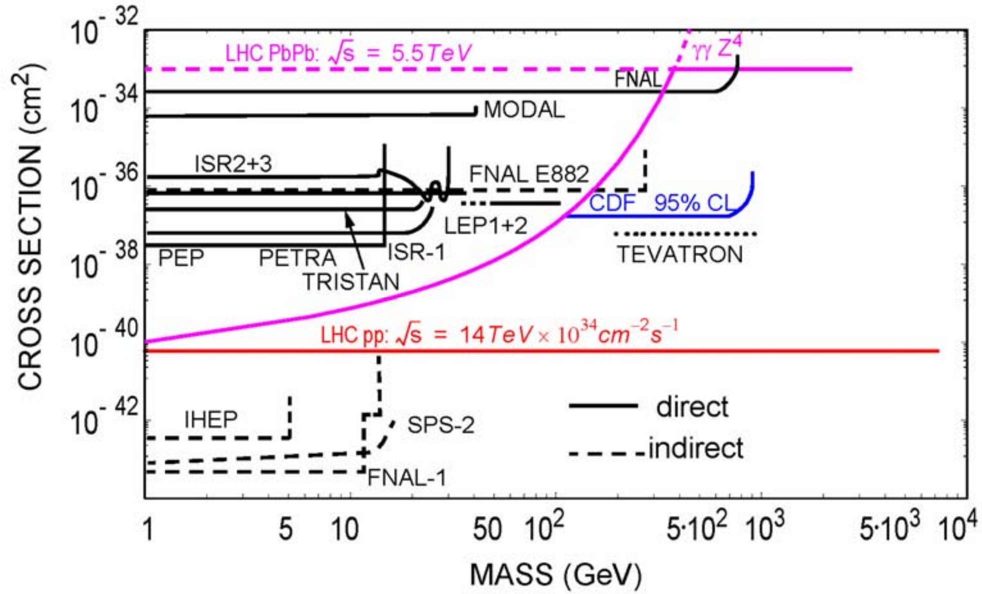
Expected Cross sections at RHIC and LHC





Published MM Experimental data

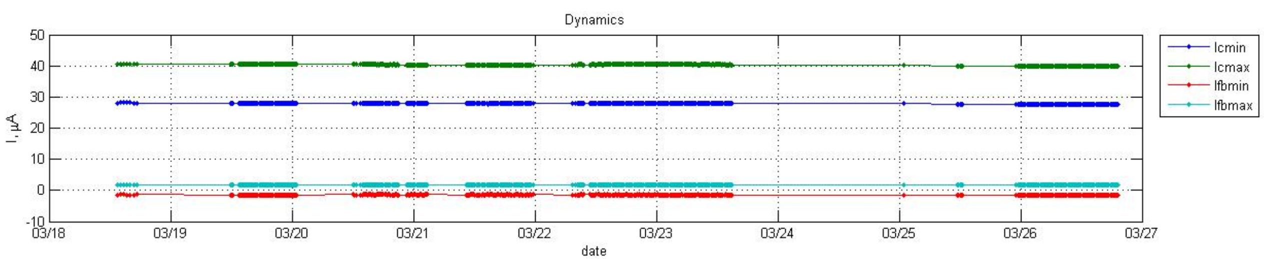


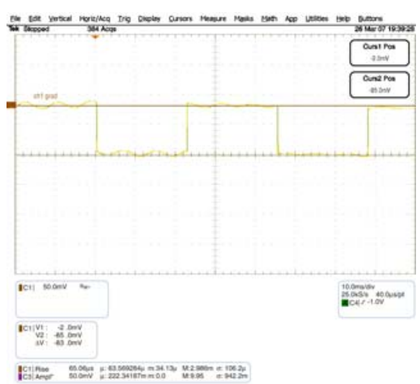


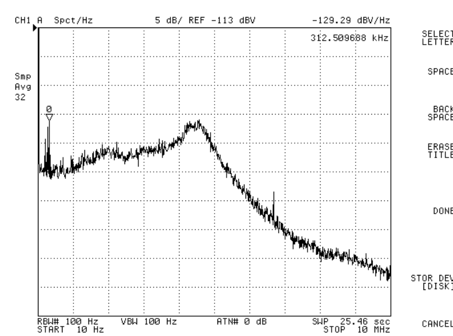
SBU Dewar installation at IR2

Experimental situation

- Two Dewars: SBU and BNL
- SBU: Storage Dewar with superconducting magnetometer and SQUID
- BNL: Dewar with two 3rd order gradiometers, two magnetometers and 4 SQUIDs







Summary

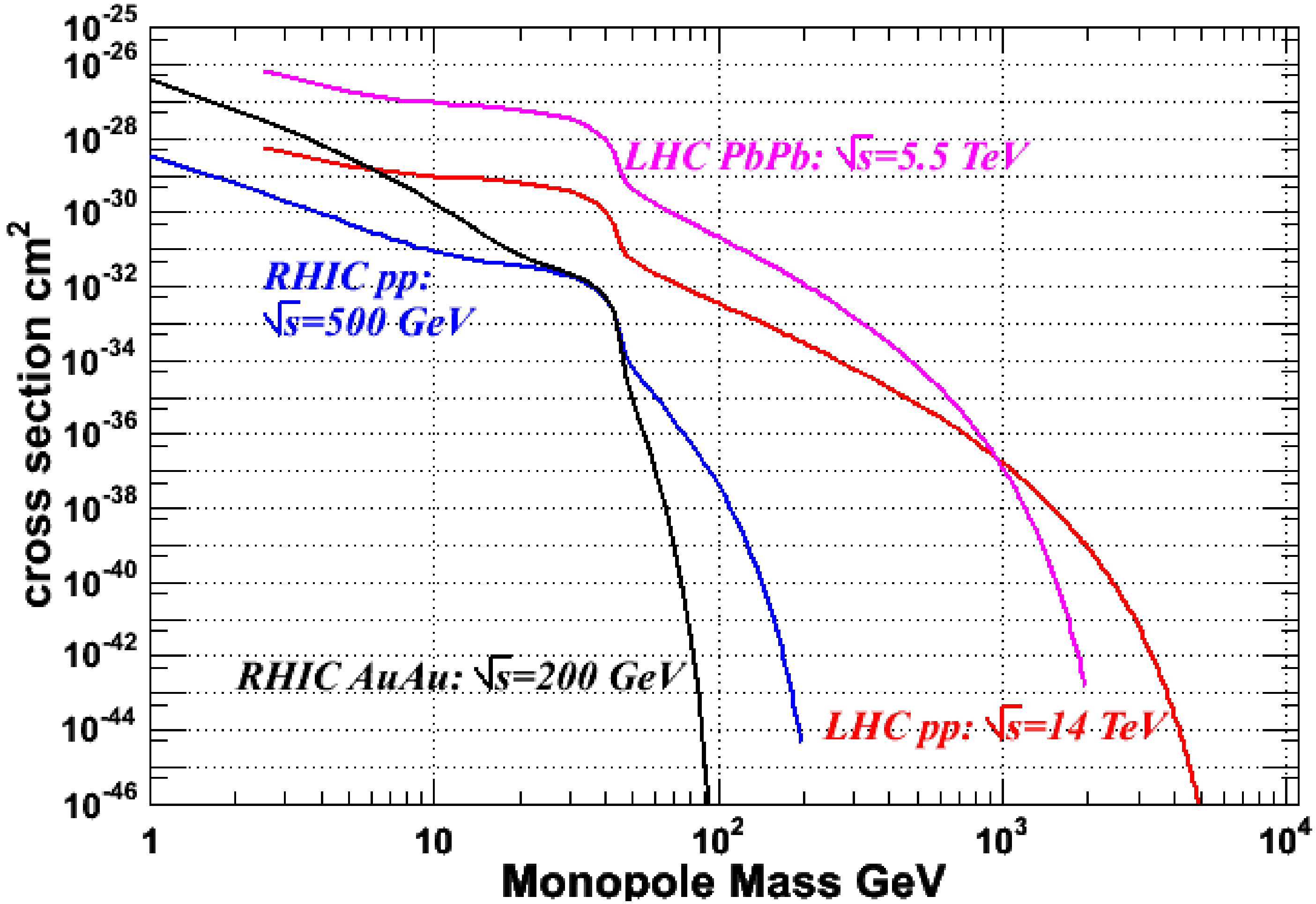
- The counterpart to the quantized elementary charge is the magnetic monopole. No monopole has been detected so far

- Our proposed search is to detect a monopole by means of its magnetic charge

- The detector can be used in future higher energy accelerators: LHC and/or ILC

Backup Slides

Drell-Yan Predictions at RHIC and LHC Energies



MMs cross section in pp interactions at RHIC and LHC

$\sigma < 3.0/(\varepsilon \int Ldt)$ one year (10^7 s)

Lstore avg = 6×10^{31} $cm^{-2}s^{-1}$ pp 100 GeV; 1.5×10^{32} cm^{-2} s^{-1} pp 250 GeV RHIC

Lstore avg = 5×10^{32} $cm^{-2}s^{-1}$ for p-p at 14 TeV LHC; ×20 ×200

Energy	Ldt (pb^{-1})	ε	σ(pb) limit	σ(cm^2) limit
100	280	0.005	2.1	2.1×10^{-36}
100	280	0.5	0.021	2.1×10^{-38}
250	1500	0.005	0.4	4.0×10^{-37}
250	1500	0.5	0.004	4.0×10^{-39}
14000	5000	0.5	0.0012	1.2×10^{-39}
14000	100000	0.5	0.00006	6.0×10^{-41}
14000	1000000	0.5	0.000006	6.0×10^{-42}

MMs cross section in AuAu ($\gamma\gamma$) RHIC and PbPb ($\gamma\gamma$) at LHC

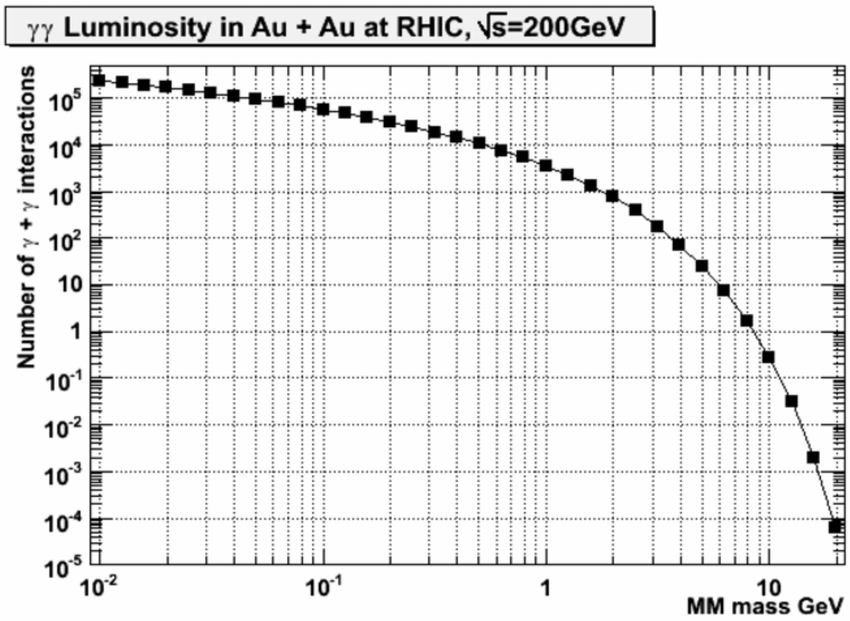
$\sigma < 3.0/(\varepsilon$ Ldt) one year (10^7 s)

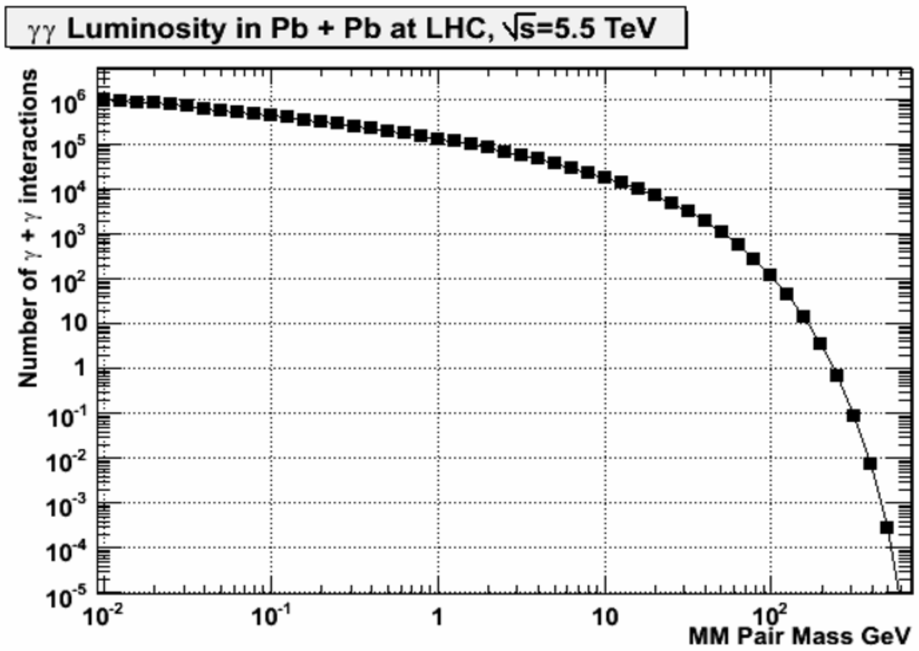
Lstore avg = 8×10^{26} cm^{-2}s^{-1} for Au-Au at 100 GeV/n RHIC

Lstore avg = 1×10^{27} cm^{-2}s^{-1} for PbPb at 5500 GeV/n LHC

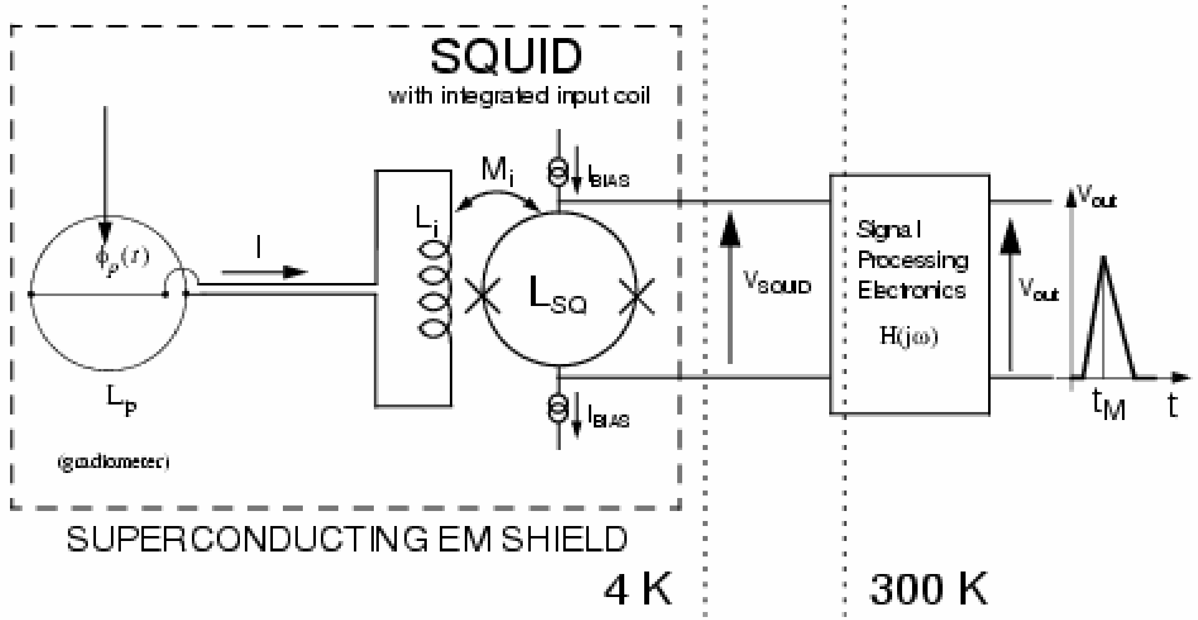
Energy	Ldt (pb^{-1})	ε	σ(pb) limit	σ (cm^2) limit
100	0.006	0.005	100000	1.0×10^{-31}
100	0.006	0.5	1000	1.0×10^{-33}
100	0.006	0.005	0.0026	2.6×10^{-39}
100	0.006	0.5	0.000026	2.6×10^{-41}
5500	0.01	0.5	600	6.0×10^{-34}
5500	0.01	0.5	0.000012	1.2×10^{-41}

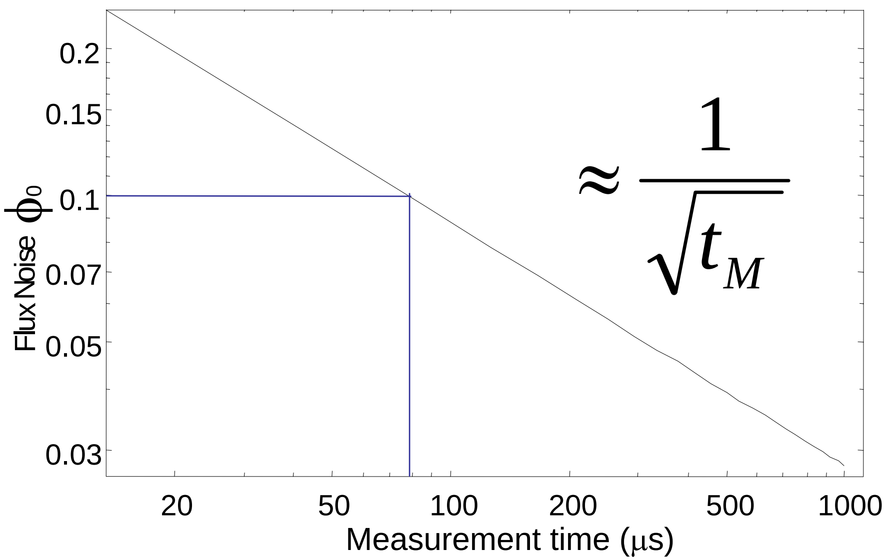
Luminosity Functions AuAu ($\gamma\gamma$), RHIC and PbPb, LHC





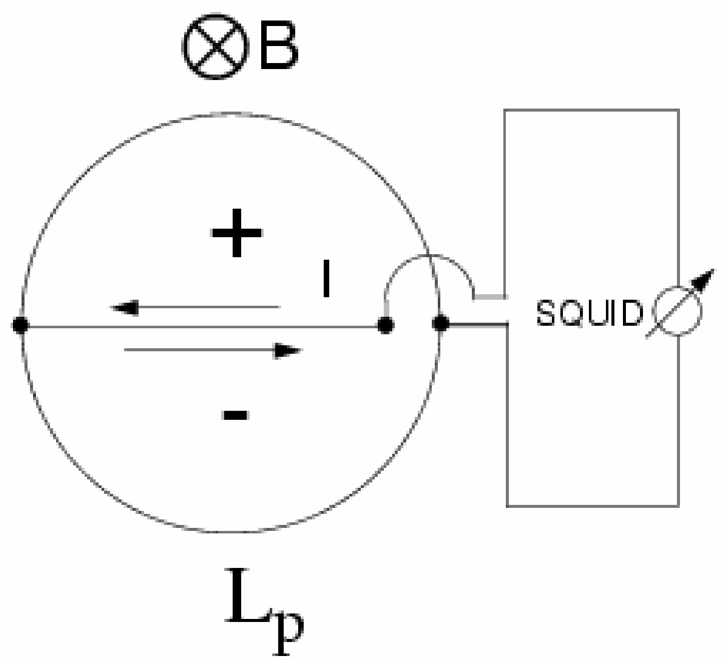
SQUID Noise





- Time resolution ~1 μs
- ~100μs measurement time needed to achieve 0.1ϕ_0 sensitivity

Gradiometer



parallel type gradiometer

- Rejects "stray" B fields but has full sensitivity to monopole signal
- Built with superconductor on Si substrate (for cooling)
- Built in quadrants to reduce inductance and fit into 30cm diameter commercial Si wafers